Department of the Navy (DON) Additive Manufacturing (AM) Implementation Plan V2.0 (2017)

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EXECUTIVE SUMMARY

The Department of Navy (DON) additive manufacturing (AM) Implementation Plan developed in accordance with the Secretary of the Navy 3 September 2015 memo, "Additive Manufacturing/3-D Printing", galvanized and aligned the DON AM community [1]. The resulting momentum led to a number of AM highlights/advancements in fiscal year 2016 (FY16):

- The first metallic flight critical part was flown on board a naval aircraft in July, 2016, and has since been certified to full performance life of the original part.
- A cross-DON energetics community aligned to advance AM of explosives, propellants, pyrotechnics and structures.
- Makerspaces deployed throughout the warfighter and civilian communities to broaden DON workforce access to digital manufacturing technology.
- Participation in a wargame to shape future industry-government business models.

This AM Implementation Plan ("AM Plan") provides an update to the FY16 document and consolidates the original SECNAV Goals into two overarching naval AM Goals: Increase Readiness/Sustainment and Enhance Warfighter Capabilities. These Goals are supported by five Objectives that represent the largest hurdles to AM adoption and align AM efforts across the DON:

1. Develop the capability to rapidly qualify and certify AM components
2. Enable end to end process integration of secure on-demand manufacturing with integrated digital AM data, infrastructure and tools
3. Formalize access to AM education, training, and certifications for the DON workforce
4. Develop responsive AM related business practices, contracting, intellectual property, legal and liability guidance
5. Enable manufacturing agility through low volume production in maintenance and operational environments

The AM Plan highlights key initiatives and articulates an execution strategy to accelerate AM implementation across the DON Enterprise. Key FY17 initiatives include:

- Identify common readiness and capability drivers across DON
- Develop initial strategy and approach to collect, manage and share AM data regarding material properties and processing
- Leverage the broader digital manufacturing community and identify AM unique cyber, cyber-physical and digital requirements
- Develop a business case model template to assess economic viability of AM components
- Continue to develop and explore the use of AM in forward deployed environments including afloat, subsurface, and expeditionary

The critical initiatives identified in this document are dependent on adequate resourcing and strong advocacy from naval leadership, in conjunction with continued broader digital design and digital manufacturing investments, in order to realize increased fleet readiness/sustainment and enhanced warfighting capabilities across the enterprise.

INTRODUCTION

Additive Manufacturing (AM) is a cross-cutting technology with significant implications for the U.S. manufacturing base and naval warfare. It can shorten the design to production cycle, enable new designs and facilitate cost effective on-demand manufacturing. Coupled with digital design and manufacturing, AM will improve warfighting systems in ways never before imagined.

There are unique Navy and Marine Corps challenges in AM that must be addressed before we can fully realize the benefit of widespread AM implementation. While there is industry and academia investment in the digital manufacturing/AM renaissance, the Naval Research and Development Establishment (NR&DE), along with Naval System Commands and key partners across the Department of Defense (DOD), are leading technical efforts to utilize AM and address unique military needs and requirements.

The Department of Navy (DON)'s AM capabilities are rapidly maturing. Complex end item manufacturing for critical components that allow previously unimagined designs for performance and efficiency is nascent but growing. Most applications today include tooling, fabrication and prototyping for more rapid conventional manufacturing processes. AM in depot operations is addressing challenges caused by obsolete, hard to source or other long lead-time components. We will continue to expand AM into routine depot maintenance and then grow into major regional expeditionary nodes.

Concurrent to the fielding of advanced AM in industrial environments, we have deployed limited polymer AM capabilities to garrison, ships and expeditionary locations to enable Sailors and Marines to address real world warfighting challenges. Expanding these uses is critical to enable digital design and manufacturing to exploit the disruptive potential of AM in military operations. The DON plans near term evaluations of more advanced AM capabilities in shipboard environments that will enable future fielding of 3D printers afloat. This aggressive pursuit of AM will ultimately enable a future "Self-Sustaining Naval Force" that is free of vulnerable lines of communication and dedicated logistics assets.

We must focus on applications that not only sustain combat operations, but generate new capabilities that can be developed only through AM. We will "weaponize" the supply chain by allowing the warfighter access to specifically tailored components, systems and munitions at the point and time of need. Though there are many milestones to complete, capitalizing on and defining the terms of AM implementation during this early stage of development will continue to maintain and expand our lead in the global competition for maritime superiority. In this new technological era, as at sea, the winds can and do change very quickly. AM will afford a level of responsiveness that realigns American military might with an emerging industrial base that is innovative, bold, and agile. Most importantly, Sailors, Marines and those who support them will be enabled to better adapt to an ever-changing global environment.

This plan identifies key actions and milestones necessary to harness this transformative technology.

PURPOSE

This AM Plan delineates the actions and coordination necessary to develop, integrate, and operationalize AM across the entire DON. This includes technology development for DON specific needs and efficiently using AM technology as it matures. Further, it includes developing AM requirements and standards for industry, developing the infrastructure to enable AM, and addressing risks unique to DON including cybersecurity and operational use. The AM Plan includes a workforce development strategy, and the alignment of supporting science and technology (S&T), research and development (R&D), acquisition, logistics and business process investments to meet DON AM Objectives. The AM Plan will enable DOD and DON organizations to leverage ongoing or planned activities, reduce redundancy, align funding opportunities and improve effectiveness of AM implementation efforts.

The AM Plan will be updated annually to reflect progress and update priorities and planning. As the AM Plan is updated, the content will evolve to include technology improvements and capture all actions necessary to achieve the AM Goals and Objectives

GOVERNANCE

Implementation and oversight of this plan will be the responsibility of the Naval Additive Manufacturing Executive Committee (NAM EXCOMM).

The NAM EXCOMM was chartered in January 2015 as a stakeholder committee to advocate for resources to support AM development, facilitate the introduction of AM capabilities across the DON, and assess the need for changes to existing policies, procedures, standards, and controls [2]. The NAM EXCOMM is tri-chaired by the Deputy Assistant Secretary of the Navy for Research, Development, Test and Evaluation (DASN (RDT&E)); the Deputy CNO for Fleet Readiness and Logistics (N4); and Deputy Commandant of the Marine Corps for Logistics and Readiness (DC I&L). Members of the NAM EXCOMM are included in the NAM EXCOMM Charter [2].

The NAM EXCOMM Working Group, comprised of Action Officers nominated by the NAM EXCOMM members, is responsible for the development and annual update of the AM Plan, tracking and execution of AM activities in their organizations, and reporting to their NAM EXCOMM leads on issues and risks.

The Naval Additive Manufacturing Technology Interchange (NAMTI) is an annual event in which AM stakeholders convene to inform NAM EXCOMM initiatives by facilitating an exchange of AM expertise, identifying current DON AM capabilities, promoting collaboration and leveraging of resources, establishing a technology baseline and developing recommendations for technology development and implementation.

COORDINATION STRATEGY

Collaboration across the DON is necessary to ensure alignment of AM activities to most efficiently achieve AM Plan Goals. While AM efforts exist across the DOD, DON, government,

academia and industry, the AM Plan focuses on DON activities and identifies key external collaborations [3]. DON AM implementation will be expedited and optimized through both engagement and formal partnership with external organizations, and by expanding collaboration opportunities throughout government, academia and industry. NAMTI not only serves as a crucial coordination enabler for DON, but also enables collaboration across these external entities.

GOALS

Additive Manufacturing provides two overarching benefits to the Navy and Marine Corps, increased readiness/sustainment and enhanced warfighting capabilities. Figure 1 is a representation of the five AM Objectives as the cross-cutting, enterprise enablers of the NAM Goals. (Examples of the types of AM capabilities that address each Goal are listed in the blue boxes under each Goal, and are not intended to be exhaustive.)

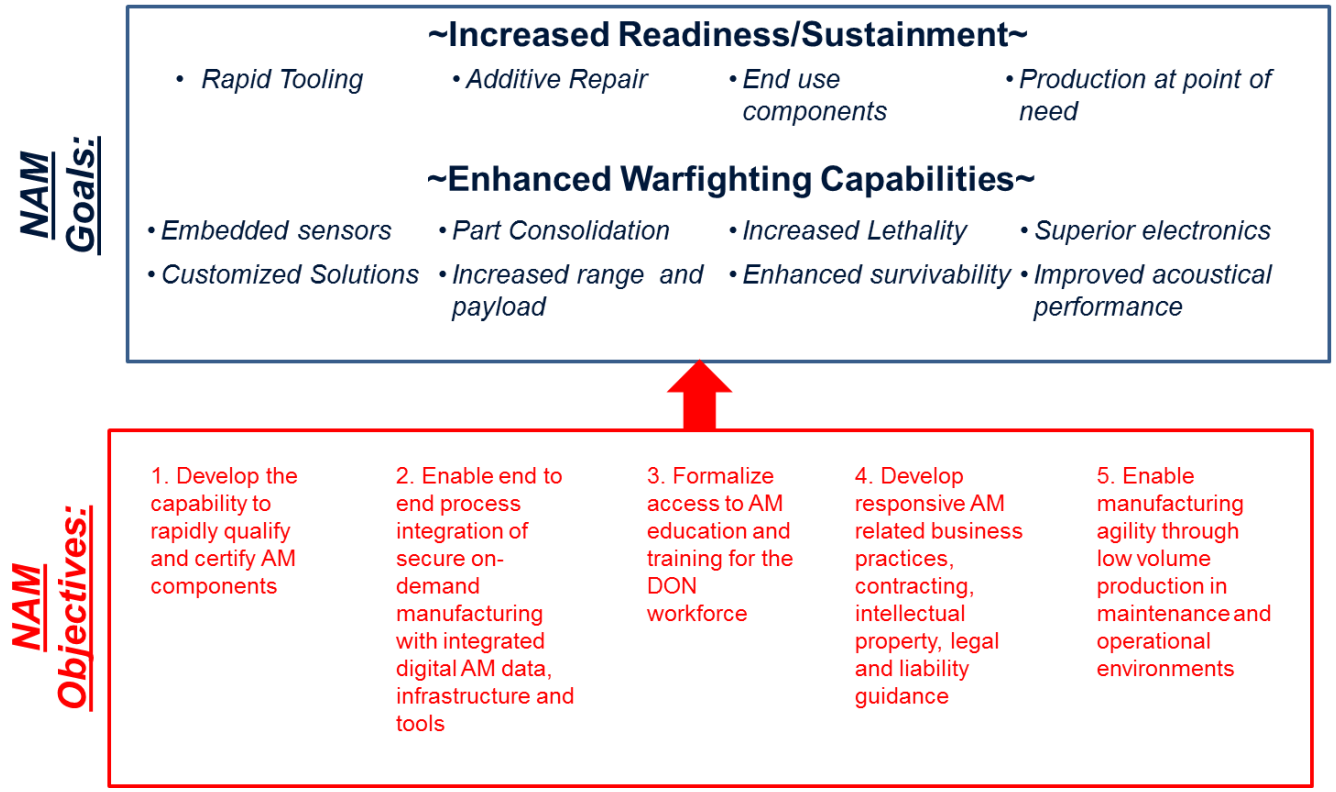

Figure 1. A depiction of the two overarching NAM Goals, examples of their utility, and the five Objectives that represent cross-cutting enablers towards realizing the Goals.

Increased Readiness/Sustainment. DON has used AM for over twenty years to produce indirect items (tooling, fixtures, molds, prototypes, etc) that make production processes more cost effective and efficient; these applications need to continue to be expanded and exploited. As AM evolves to be used for the production of end-use components, there is significant potential for AM to resolve obsolescence and long lead time issues. The eventual production of components

'on demand' and close to the point of need will support a robust, scalable supply chain and allow a new era of supply chain independence.

Enhanced Warfighting Capabilities. AM eliminates traditional design constraints, creating a new design space that allows for previously unobtainable design characteristics. Multi-component assemblies can be consolidated into a single item, lattice-like structures will yield lighter and stronger parts, advanced materials enable multi-functionality, miniaturized sensors can be embedded into a structure – all resulting in more effective and more lethal platforms. AM also allows for widespread customization, enabling tailored solutions that are specific to each mission or even each warfighter.

It is important to note that, through rapid prototyping, AM accelerates capability development which helps to address urgent needs, drive innovation at the speed of battle, and deliver advanced warfighting capabilities. These benefits are realized in both readiness and enhanced capabilities.

IMPLEMENTATION STRATEGY

The AM Plan maps all AM activities from each NAM EXCOMM organization to the AM Plan Goals and Objectives.

The five Objectives encompass hurdles that are crucial to overcome in order to accelerate AM adoption. Each Objective, which serves as an enterprise enabler of the technology, is defined and given an end-state wherein the Objective is considered achieved. Key foundational initiatives are then proposed for FY17 and FY18 in order to ensure progress towards achieving the Objective. As this Plan is amended in future years, the Plan content will evolve with fast-paced technology progressions and new AM applications to reflect the necessary actions to achieve each Objective and ensure AM activities are coordinated collaboratively across the DON. AM Objectives are further decomposed into Focus Areas to enable phasing/prioritization of AM initiatives within each Objective, a comprehensive list of AM activities within each Objective is detailed in Appendix A.

Targeted technology demonstrations that can leverage AM for enhanced readiness and capabilities are critical to ensuring and enabling continued coordination of the work needed to achieve each of the Objectives. These demonstrations are often cross-cutting, inform the needs of multiple Objectives and assist in the identification of key gaps to accelerated AM adoption. Further, component demonstrations serve to showcase the impact enabled by AM to multiple applications and therefore help to challenge cultural barriers associated with AM implementation. Near term, targeted AM demonstrations that will exhibit AM benefits regarding increasing readiness and capabilities while informing multiple Objectives are included in Appendix B.

It should be noted that as this plan is executed multiple targets of opportunity will emerge beyond those listed in this document that will result in progress towards achieving the NAM Goals and/or providing demonstrations of the Objectives. These opportunities will be aggressively pursued and coordinated throughout DON.

Notable FY16 AM accomplishments are included in Appendix C.

Objective 1: Develop the capability to rapidly qualify and certify (Q/C) AM components

Definition. Qualification and certification (Q/C) are necessary to ensure that AM components will meet requirements of naval systems. Qualification is the demonstrated capacity to consistently produce properties or performance[1]. Certification is approval by an authorized representative that a part meets the characteristics required to perform satisfactorily in its intended application[2]. Q/C of AM also encompasses repair procedures and development of rapid non-traditional approaches that will accelerate the qualification and certification process.

To realize AM's substantial capability, significant R&D, including S&T, is required to ensure affordable, reliable use of AM. Current technologies and approaches for qualification and certification are ill-suited for AM components, which are produced unit-by unit in low-volumes with limited confidence in material, processing history, and component geometry/tolerances. These technical challenges, such as robust, accelerated Q/C processes and naval material and manufacturing advancements, are addressed within the needs associated with this Objective; an explicit list is included in Appendix A.

End-State. A framework developed to enable accelerated Q/C of components at a lower cost than is currently possible, thereby providing reasonable assurance those components will perform to meet their performance requirements.

Path Forward. The following denotes high priority, near term enterprise level initiatives to be accomplished in FY17 and FY18 in order to ensure progress towards achieving Objective 1. A comprehensive list of implementation challenges to achieving this Objective can be found in Appendix A.

FY17:

1. Identify common readiness and capability drivers across DON
2. Leverage existing Naval SYSCOM technology demonstration efforts to support accelerated framework for Q/C
3. Develop initial strategy and approach to collect, manage and share AM data regarding material properties and processing

FY18:

1. Map Q/C requirements applicability across SYSCOMS for critical applications
2. Begin execution of strategy to collect and manage AM material process and property data

[1]Qualification requires placing controls on facilities, materials, equipment, processes, policies, and personnel as appropriate. For critical applications or those with severe service condition levels, statistically substantiated properties for material and process qualification must be demonstrated

[2] The part must be made using a qualified material and process. The criticality or service condition level of the part, its performance requirements, and operational environment dictate the type and extent of testing required. Parts in critical applications or those with severe service condition levels are certified only after testing them in the assembled condition at the subsystem or system level.

Objective 2: Enable end to end process integration of secure on-demand manufacturing with integrated digital AM data, infrastructure and tools

Definition. As a digital manufacturing technology, AM requires managing vast amounts of digital data for effective implementation. This digital data is needed for a number of digital manufacturing processes, of which AM is a subset, and this Plan will focus on digital manufacturing from an AM perspective. The digital AM framework includes the IT architecture and infrastructure, tools, cybersecurity, digital data standards (including design), data acquisition, and management required to utilize AM across the Naval Enterprise. Ensuring standardized and secure AM data will accelerate DON lifecycle processes and expand use of AM technology.

End-State. Standardized and secure AM data and infrastructure that enable acceleration of DON lifecycle processes.

Path Forward. The following denotes high priority, near term enterprise level initiatives to be accomplished in FY17 and FY18 in order to ensure progress towards achieving Objective 2. A comprehensive list of implementation challenges to achieving this Objective can be found in Appendix A.

FY17:

1. Develop process to continuously assess readiness drivers across all platforms that may benefit from AM Applications
2. Baseline DON AM capacity across AM Application Space
3. Initiate development of standardized data architecture/security/interfaces for AM
4. Leverage the broader digital manufacturing community and identify AM unique cyber, cyber-physical and digital requirements

FY18:

1. Standardize process and repository to manage/secure AM Technical Data Packages (TDPs)
2. Publish strategy for managing licensing requirements for commercial AM TDPs, including tracking required payments
3. Formalize AM unique cyber, cyber-physical and digital requirements

Objective 3: Formalize access to AM education, training, and certifications for the DON workforce

Definition. Training the DON workforce in AM encompasses all development, deployment, and utilization of AM education, training, and certification programs and opportunities to ensure that the DON workforce (both civilian and military) can safely and effectively use AM, leveraging these technologies along with digital design capabilities, to the fullest capacity. This includes training and education of and for the R&D, Acquisition, Operational, Business, and Sustainment communities, plus investing and leveraging Science, Technology, Engineering, and Mathematics (STEM) for the future workforce accessions and innovation activities across the DON.

End-State. A 21st century workforce capable of capitalizing on AM benefits, capabilities, and emerging technologies.

Path Forward. The following denotes high priority, near term enterprise level initiatives to be accomplished in FY17 and FY18 in order to ensure progress towards achieving Objective 3. A comprehensive list of implementation challenges to achieving this Objective can be found in Appendix A.

FY17:

1. Continue to conduct broad AM familiarization training and STEM activities
2. Introduce new makerspaces into DON to expand access and education of AM technologies
3. Ensure makerspaces become a vital part of workforce training by developing communication plan to inform leadership of current and future implications of AM technologies, and to foster an atmosphere of innovation in the DON

FY18:

1. Develop DON requirements for a current workforce training program
2. Leverage AM incorporation within Defense Acquisition University initiatives to broaden AM training of DON workforce

Objective 4: Develop responsive AM related business practices, contracting, intellectual property, legal and liability guidance

Definition. The understanding of necessary business models (contracting language, intellectual property considerations, liability concerns, etc) to support AM is rapidly evolving as the technology is more widely adopted and employed. DON must posture itself to ensure these considerations are addressed in order to ensure the rapid adoption of AM.

End State. Agile business processes that allow the responsive incorporation of AM into DON.

Path Forward. The following denotes high priority, near term enterprise level initiatives to be accomplished in FY17 and FY18 in order to ensure progress towards achieving Objective 4. A comprehensive list of implementation challenges to achieving this Objective can be found in Appendix A.

FY17:

1. Partner with Defense Logistics Agency to determine inventory of parts for introduction into supply chain
2. Conduct second AM business process wargame with DOD, industry and academia to inform contracting, legal, intellectual property and liability guidance
3. Develop business case model template to assess economic viability of AM components

FY18:

1. Introduce selected parts into supply chain
2. Publish guidance providing direction towards obtaining AM digital data early in acquisition cycle
3. Determine if existing contracting structures support AM integration

Objective 5: Enable manufacturing agility through low volume production in maintenance and operational environments

Definition. In order to fully realize the potential of AM to shorten the logistics tail, the technology needs to move outside of laboratories and depots to be employed close to the point of need: afloat, subsurface, expeditionary, forward deployed, etc. In doing so, equipment is exposed to a number of environmental conditions that must be considered. This Objective encapsulates all the considerations necessary to ensure reliable production in any operational environment.

End State. The ability to use AM to manufacture needed items in any location.

Path Forward. The following denotes high priority, near term enterprise level initiatives to be accomplished in FY17 and FY18 in order to ensure progress towards achieving Objective 5. A comprehensive list of implementation challenges to achieving this Objective can be found in Appendix A.

FY17:

1. Develop candidate applications for production in operational environments
2. Continue to develop and explore the use of AM in forward deployed environments including afloat, subsurface, and expeditionary

FY18:

1. Determine initial integration requirements for afloat/expeditionary environments
2. Baseline AM system performance in dynamic/operational environments
3. Simulate AM capability in operational environment with integration technologies incorporated
4. Publish afloat AM guidelines/impact assessment

CONCLUSION

This AM Plan, in conjunction with broader digital manufacturing investments, provides a comprehensive path to effectively and efficiently integrate AM across the DON Enterprise. The essential initiatives identified in this document are dependent on adequate resourcing and strong advocacy from naval leadership. DON will utilize this AM Plan while continuing to leverage critical collaborations to realize increased fleet readiness/sustainment and enhanced warfighting capabilities across the enterprise.

REFERENCES

[1] Department of the Navy (DON) Additive Manufacturing Implementation Plan (2016)

[2] Naval Additive Manufacturing Executive Committee Charter 1.0, January 2015

[3] *Manufacturing USA* – the National Network for Manufacturing Innovation. https://www.manufacturing.gov/nnmi/

APPENDIX A – OBJECTIVE TABLES

The tables below present a detailed list of the challenges to achieving each of the Objectives. Within each table, broad challenges that need to be overcome – Focus Areas – have been identified. Within each Focus Area, Project Descriptions have been defined that are critical to implementation of additive manufacturing (AM) technology.

It is noteworthy that Objective 1 addresses, from a broad perspective, technical challenges which currently limit the widespread adoption of AM. Most if not all of the Project Descriptions are indicative of the types of efforts that will continue past the Objective 1 end-state for developing the framework to enable accelerated qualification and certification at a reduced cost. Efforts are needed for developing/expanding the AM library of materials, developing and optimizing AM processes and post-processes for distinct component requirements and developing new qualification and certification techniques that overcome limitations to conventional approaches. Further, in addition to the breadth of materials/ processes/ scenarios currently envisioned, the field and application of AM is going to continue to advance well into the future, presenting new unexpected opportunities and challenges.

Table 1. Objective 1: Develop the capability to rapidly qualify and certify AM components

Implementation Challenges to be Overcome	
Focus Area	**Project Description**
1.1 Broader Library of Materials for Naval AM Use	1.1.1 Develop criteria for AM metals feedstock material
	1.1.2 Develop and optimize new materials for AM
	1.1.3 Develop criteria for AM polymers feedstock material
	1.1.4 Develop criteria for AM elastomers feedstock material
	1.1.5 Develop criteria for AM ceramic feedstock material
1.2 Pre and Post Processing	1.2.1 Develop criteria for AM specific pre and post-processing for property modification
	1.2.2 Develop AM specific finishing processes
	1.2.3 Develop criteria for assessing AM processes
1.3 Material Properties	1.3.1 Establish link between as fabricated AM process, environment, microstructure, and resulting properties
	1.3.2 Establish a link between post-processing, microstructure, and resultant properties
	1.3.3 Develop computational modeling to reduce amount of required testing for qualification and certification
	1.3.4 Develop modeling and simulation to open up design space
1.4 Quality Assurance	1.4.1 Identify AM specific defects and establish link between defects and properties
	1.4.2 Develop criteria for inspection techniques that can be used on AM parts
1.5 Standards and Specifications Development	1.5.1 Establish operator standards
	1.5.2 Establish procedure and process qualification standards
	1.5.3 Establish machine and calibration qualification standards
	1.5.4 Establish essential variables/parameters for AM processes
	1.5.5 Establish material standards
	1.5.6 Establish Quality Assurance standards
	1.5.7 Establish AM joining and repair standards
1.6 Manufacturing Process Control	1.6.1 Develop criteria for in-situ control
	1.6.2 Develop criteria for material re-use (for all materials and forms)
	1.6.3 Develop criteria for AM modeling and simulation tools to inform manufacturing
End-Sate: A framework developed to enable accelerated Q/C of components at a lower cost than is currently possible, thereby providing reasonable assurance those components will perform to meet their performance requirements.	

Table 2. Objective 2: Enable end to end process integration of secure on-demand manufacturing with integrated digital AM data, infrastructure and tools

Implementation Challenges to be Overcome	
Focus Area	**Project Description**
2.1 Digital Data Standards and Management with Incorporated AM Requirements	2.1.1 Develop and demo standards incorporating AM technical data for non-critical parts
	2.1.2 Develop and demo standards incorporating AM technical data for critical parts
	2.1.3 Develop data repository architecture and management approach with AM data
	2.1.4 Develop interface standards for AM data with industry
2.2 Digital Manufacturing Framework Development and Deployment with Incorporated AM Requirements	2.2.1 Test Beds and experimentation on Joint Advanced Manufacturing Region IPT
	2.2.2 Develop and demonstrate process for building digital data incorporating AM data
	2.2.3 Prototype and/or deploy digital framework across DON and develop use case and requirements for AM
	2.2.4 Develop design requirements for manufacturing network implementation
2.3 Digital Manufacturing Data Acquisition Support with Incorporated AM Requirements	2.3.1 Develop policy, process, and standards to acquire digital data to enable AM across all DON systems
	2.3.2 Demonstrate direct interface between industry and DON to manage AM data
2.4 On Demand Production Strategy and Architecture	2.4.1 Evaluate the NIST Reference Architecture for cyber physical systems for implementation in manufacturing nodes
	2.4..2 Evaluate, test, and implement current eCommerce and eProcurement contractual mechanisms
2.5 Cyber Requirements and Implementation	2.5.1 Develop cyber use case and requirements
	2.5.2 Establish the end-to-end criteria needed to comply with Authority to Operate (i.e. digital content devices, TTPs, networks, and communication links)
	2.5.3 Determine Certification and Accreditation organizational responsibilities in accordance with DON CYBERSAFE and related DON/DOD policies
	2.5.4 Perform cyber red-team assessment on AM systems and infrastructure
	2.5.5 Determine digital manufacturing security architecture to support AM
2.6 Design through Sustainment Acceleration Strategy and Management	2.6.1 Develop AM design tool requirements and integrate
	2.6.2 Develop AM closed loop control requirements and integrate
	2.6.3 Develop validated AM tools/machine baseline
	2.6.4 Develop AM modeling and simulation tools baseline capabilities
	2.6.5 Validate AM producer capabilities and interface to digital manufacturing framework
End-State: Standardized and secured AM data and infrastructure that enable acceleration of DON lifecycle processes.	

Table 3. Objective 3: Plan to formalize access to AM education, training, and certification for the DON workforce

Implementation Challenges to be Overcome	
Focus Area	**Project Description**
3.1 Current Workforce Training	3.1.1 Develop broad AM familiarization training
	3.1.2 Identify means to increase workforce access to Maker Spacers and Fabrication Laboratories (FABLAB)
	3.1.3 Develop designer training
	3.1.4 Develop Accelerated Learning Centers
	3.1.5 Develop training and certification process for users/operators
	3.1.6 Identify Navy rating, USMC military occupational specialty, and associated learning centers
	3.1.7 Develop maintenance activity support training
	3.1.8 Develop warfighter training
	3.1.9 Develop training for expeditionary spaces
3.2 Future Workforce Training	3.2.1 Engage Science, Technology, Engineering, and Math (STEM) programs
3.3 Workforce Metrics	3.3.1 Measure impact of AM training for the warfighter, designers, and maintenance support
End-State: A 21st century workforce capable of capitalizing on AM benefits, capabilities, and emerging technologies.	

Table 4. Objective 4: Develop responsive AM related business practices, contracting, intellectual property, legal and liability guidance

Implementation Challenges to be Overcome	
Focus Area	**Project Description**
4.1 Supporting Business Functions	4.1.1 Determine necessary changes needed to enhance and streamline supply chain management processes, business logic, and policies to take advantage of AM order fulfillment from start to finish
	4.1.2 Determine if existing contracting structures support AM integration; propose any needed new language and constructs
	4.1.3 Examine various licensing structures for intellectual property
	4.1.4 Identify key functions within Logistics Information Technology and enterprise-level business systems including ERP for upgrade and improvement
	4.1.5 Determine if print on demand can be instituted without human generation of individual delivery or purchase orders
4.2 Intellectual Property	4.2.1 Assess existing FAR and DFAR clauses for revision or propose new ones to accommodate the unique aspects of AM
	4.2.2 Examine Intellectual Property Laws and Data Rights categories for potential AM related acquisition gaps
	4.2.3 Understand potential complications of government-industry partnerships due to liability and how to resolve
4.3 Life Cycle Sustainment Planning	4.3.1 Determine how product life cycle sustainment and integrated product support requirements can accommodate AM
	4.3.2 Develop cost modeling for comparison of traditional manufacture versus AM to include reductions in administrative and production lead times
End State: Agile business processes that allow the responsive incorporation of AM into DON.	

Table 5. Objective 5: Enable manufacturing agility through low volume production in maintenance and operational environments

Implementation Challenges to be Overcome	
Focus Area	**Project Description**
5.1 Maintenance Operations	5.1.1 Determine candidate applications amenable to AM in depot and IMF applications
	5.1.2 Increase use of AM for indirect applications (tooling, fixtures, etc) in proper applications
5.2 Manufacturing in Operational Environments (Afloat/Subsurface/ Expeditionary/Forward Deployed)	5.2.1 Determine candidate components for manufacturing in operational environments
	5.2.2 Develop sensor package to study operational environments and deploy with targets of opportunity (fab labs, etc)
	5.2.3 Develop ability to cost effectively replicate operational environments
	5.2.4 Determine candidate platforms for integration and perform integration studies
	5.2.5 Determine operational environment effects on material properties, processes and procedure qualification
End-Sate: The ability to use AM to manufacture needed items in any location	

APPENDIX B – MILESTONES

The steps towards achieving each of the Objectives will occur in stages with the maturation of additive manufacturing (AM) and associated enabling efforts. The current maturity of AM is heavily dependent on not only the material and specific AM process chosen, but also the necessity of digital tools, networks, cyber requirements, business support guidance, workforce training, etc., for the chosen application. A specific Technology Readiness Level cannot be applied to the whole of AM; some areas and applications remain at an academic research level while other applications are in the process of being transitioned to the Fleet. Given that the various aspects of AM acquisition, business, cyber, technology, and workforce are at different maturity levels, the levels of demonstrations of AM technology are expected to occur gradually.

The milestones listed in **Figure** 1 below denote anticipated progression towards achieving each Objective. These anticipated milestones and timeframes can be expected to shift and evolve over time as the technology advances and AM applications increase. Regardless, the milestones will serve to track AM progress towards achieving each Objective.

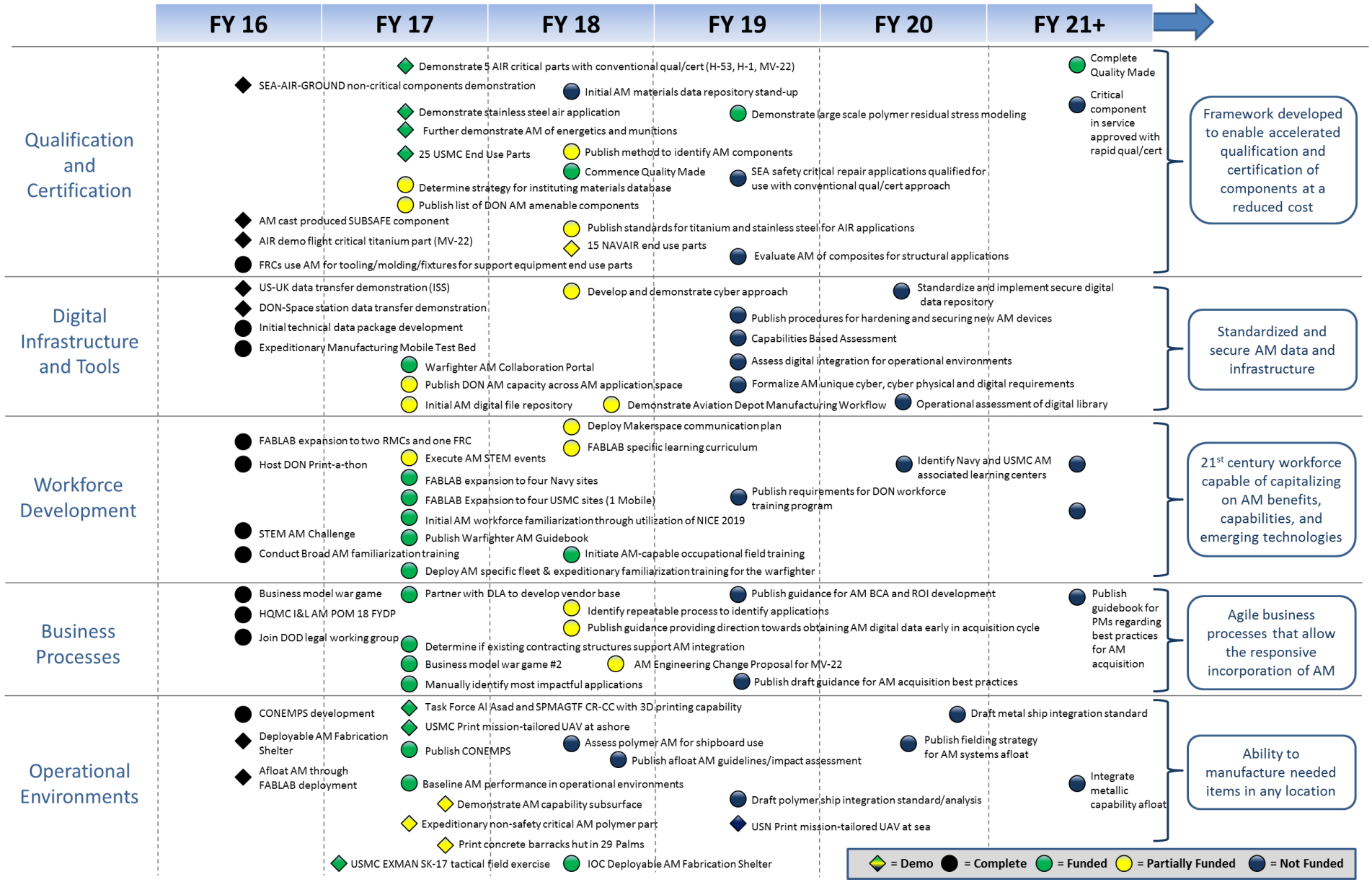

Figure 1. Progression Milestones and Demonstrations

APPENDIX C: SUMMARY OF 2016 AM ACCOMPLISHMENTS

Enterprise Accomplishments:

- Department of Navy (DON) initiated development of the naval additive manufacturing (AM) concepts of employment (CONEMPS). This product will describe future AM enabled capabilities using a number of vignettes and will be used to inform an enterprise-wide investment strategy. The CONEMPS will be available online in February 2017.
- New AM applications and opportunities are constantly being identified and several efforts have initiated since the development of the Implementation Plan. These efforts will provide enhanced warfighting capabilities and faster design through rapid prototyping and experimentation related to a number of applications. Projects have initiated throughout the past year that incorporate the printing of unmanned systems tailored to specific missions, energetic materials and custom fragmentation patterns in munitions, medical prosthetics and custom cranial implants, and the exploration of signature reduction through new, innovative designs. The printing of sand molds is being explored for cast components, which will demonstrate how AM can significantly reduce lead times for metallic part production.
- The Deputy Assistant Secretary of the Navy for Research Development Test and Evaluation sponsored Print-A-Thon was held at Naval Surface Warfare Center, Dahlgren Division on 20 April, 2016. Twenty five additively manufactured items were produced by installations throughout the Naval Research and Development Establishment and displayed at the event. In addition to demonstrating the wide spectrum of creative and innovative designs enabled by AM, the event offered a forum for AM subject matter experts to share lessons learned and develop future collaboration opportunities. The 2017 Print-A-Thon will be held in the Pentagon in March 2017.
- Headquarters Marine Corps Installations and Logistics has built a dedicated team for AM and is pursuing a Program Objective Memorandum for the Five-year Defense Plan that initiates in fiscal year 2018.

Collaboration Initiatives:

- DON formed an energetic materials working group in order to produce a collaborative, DON roadmap for advancement of AM to support the production of explosives, propellants, pyrotechnics, and structures.
- DON organized and participated in the third annual Naval Additive Manufacturing Technology Interchange, which included 300 government and industry participants and took place from 7-9 June 2016.
- DON participated in a Department of Defense road mapping effort to align AM initiatives and needs across the services.
- The Joint Advanced Manufacturing Region integrated product team, a Navy-led, Interagency and Industry Team focused on design, testing, security and integration requirements for the emerging smart manufacturing grid continues to share best practices and lessons learned.

Objective 1: Develop the Ability to Qualify and Certify AM Parts

- A V-22 flight critical titanium component produced via AM was installed and flown in July, 2016 and has since been certified to full performance life of the original part. This demonstration illustrates the potential of increasing the Navy's operational availability through additively manufactured end use metallic components. Future demonstrations will optimize the component design through topology optimization to produce lighter weight geometries.

- The Office of Naval Research Future Naval Capability project Quality Made has been approved to begin in Fiscal Year 2018 and is currently under solicitation. This effort is foundational in developing confidence in metal AM processes and in the DON's incorporation of predictive materials modeling that will allow for more rapid qualification and certification of metal AM materials.
- Several projects are underway to evaluate the behavior of multiple AM materials produced by AM processes. These processes span Technology Readiness Levels 2-8 and include biological, polymer, metallic and ceramic materials. As an example, one DON project is utilizing additive manufacturing to manufacture large scale polymer bow and hull sections of wet combat submersibles and unmanned underwater vehicles. The material properties (such as residual stress) generated through this and similar efforts will be leveraged in future initiatives.

Objective 2: Enable end to end process integration of secure on-demand manufacturing with integrated digital AM infrastructure and tools

- A DON project incorporating a preliminary technical data package into the naval supply system was initiated that will identify gaps that need to be addressed in order to implement a digital AM framework.
- The Expeditionary Manufacturing Mobile Test Bed, a joint Navy and Marine Corps project, has embedded advanced manufacturing equipment within an operational Marine Corps maintenance battalion to develop and test Standard Operating Procedures that will become future advanced manufacturing techniques, tactics and procedures.

Objective 3: Formalize Access to AM Education, Training, and Certifications for the DON Workforce

- Fabrication laboratories (FAB LABs) have been approved to be deployed to sites throughout the Navy and Marine Corps in order to train the warfighter in advanced manufacturing capabilities. The first mobile FAB LAB was delivered to the Navy in June and was showcased at the National Maker Faire in Washington D.C. 18-19 June. This is a Fleet Readiness Center East asset, the second and third mobile FAB LAB trailers were delivered in September to support Regional Maintenance Centers in Mayport, FL and San Diego, CA. Additional FAB LABs have been funded and are expected to be delivered in FY17.
- During USS HARRY S. TRUMAN's deployment to 5th Fleet, the crew utilized an onboard FAB LAB to design a repair solution to the plastic housing on handheld radios that won the Project Apollo Hatch Challenge.
- Numerous ad-hoc training programs are teaching 3D design and printing to our Marines, Sailors and civilian workforce, already yielding innovative use cases for low-end prototyping and fabrication.
- The Naval Research and Development Establishment's Naval Innovative Science and Engineering 219 portfolio includes several AM projects. In addition to advancing the technology, these efforts are also crucial to developing an educated technical workforce that can more rapidly adopt the technology.

Objective 4: Develop responsive AM related business practices, contracting, intellectual property, legal and liability guidance

- Current conventional or industry business profit models may not be compatible with broad implementation and use of additive manufacturing capabilities. However, additive manufacturing may create opportunities and pathways to improve the alignment between the Department's cost and performance interests and the revenue and profit interests of commercial providers. To examine this issue more closely, DON participated in a joint, government and industry war game that began to address the business support functions needed to fully

embrace AM implementation. The development of business models amenable to the industrial base and taxpayer, necessary contracting actions, liability and intellectual property infringement were addressed.

- DON lawyers joined an Office of the Secretary of Defense sponsored intellectual property (IP) AM working group and this entity continues to discuss the ramifications of IP and AM.

Objective 5: Enable manufacturing agility through low volume production in maintenance and operational environments

- In addition to increasing workforce access to makerspaces, the deployment of Fab Labs has resulted in lessons learned regarding the shipboard use of AM equipment. These are crucial first steps to understanding shipboard environments on AM.
- A project is underway aiming to deploy introductory AM equipment subsurface with the goal of printing onboard a submarine in spring of 2017.

APPENDIX D: DOCUMENT AUTHORS

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